INTRODUCING NEW TECHNOLOGIES AND MARKETING STRATEGIES FOR HOUSEHOLDS WITH MALNUTRITION: AN ETHIOPIAN CASE STUDY

by

Yigezu A. Yigezu and John H. Sanders

Working Paper #08-05

Revised May 14, 2008

Dept. of Agricultural Economics

Purdue University

INTRODUCING NEW TECHNOLOGIES AND MARKETING STRATEGIES FOR HOUSEHOLDS WITH MALNUTRITION: AN ETHIOPIAN CASE STUDY

by
Yigezu A. Yigezu and John H. Sanders
Dept. of Agricultural Economics, Purdue University
West Lafayette, Indiana 47907-2056
yyigezu@purdue.edu and jsander1@purdue.edu
Working Paper # 08-05
May 2008

Abstract

Many developing regions have excellent potential agricultural resources. However, historically population has become so concentrated on such small holdings that acute poverty and malnutrition now predominate. The food scientists' response to the chronic nutritional problem has often been subsidized bio-fortification with nutritional supplements or more recently cultivars with higher nutrient levels. Where much of the population is in this inadequate nutrition category as in highland Ethiopia, the supplements are neither financially feasible nor sustainable. The cultivars can provide a few critical nutrients but are not a comprehensive solution. To improve nutrition, it is necessary to increase income so that an increased quality and quantitative diet can be obtained. Here we evaluate a strategy to introduce new agricultural technologies where a central aspect of evaluation is combining the nutritional and income goals. This analysis is undertaken in the Qobo valley, Amhara state, Ethiopia. Using behavioralist criteria for decision making defined by the farmers, the effects of different potential combinations of technologies and supporting agricultural policies on the household nutritional gaps and farmers' incomes are analyzed. An integrated approach involving the combined technologies of water harvesting, fertilization and Striga resistance combined with improved credit programs has the potential to increase income by 31% and to eliminate malnutrition except in the most adverse state of nature (10% probability). Both the treatment of the nutritional deficits and the decision making criteria defined by farmers are expected to be useful techniques in other developing country technology and policy analysis as well.

Key words: Adoption, agricultural technologies, *Striga* resistance, inorganic fertilizers, tied-ridges, marketing strategies, inventory credit, nutrition, income, capped-lexicographic utility.

JEL Codes: O13, O33, Q16, Q18

1. Introduction

There continues to be tension among policy-makers on the choice between broad-based economic policies as a means of eliminating malnutrition, and the use of more targeted interventions as with bio-fortified drinks or crops (Welch and Graham, 1999; ACC, 1997; Bouis, 1996; Divender, 2007; Underwood, 1999; IFPRI, 2002). The introduction of agricultural technologies that focus both on increasing the caloric intakes and the incomes of smallholder farm households in impoverished regions needs to be a high priority for many developing regions.

Much of rural poverty is concentrated in better resource based but over populated regions with malnutrition problems. The population pressure then leads to the vicious cycle of low incomes and underinvestment in agricultural technologies leading to poor nutrition and insufficient investment in human capital. In these high resource regions, new agricultural technologies have substantial potential to not only provide the needed energy to family members but also by raising their incomes to increase their access to other foods so that they can balance their diet with their increased purchasing power.

In this paper, we evaluate the farm household welfare effects (nutrition and income) in the Amhara region of Ethiopia of a national project to introduce new technologies including, inorganic fertilizer, water harvesting techniques, and *Striga* resistant sorghum cultivars. The effects of the individual and the combined use of these technologies are assessed along with an improved marketing strategy to accelerate technology adoption.

With the large seasonal price swings of cereal staples, farmers often sell at the annual price lows and then repurchase when prices are high and only limited supplies are available. Combining technology introduction with a marketing strategy to increase prices received then enables farmers to purchase the higher levels of inorganic fertilizer needed to overcome the soil fertility problems. Inventory credit is designed to enable farmers to benefit from the seasonal price variation characteristic of food staples in much of the developing world by providing credit at harvest with the collateral being the cereal staple. Farmers retain cereal ownership and then can sell later and repay the credit, plus interest and storage costs. The benefits of inventory credit are also compared with input credit, a principal policy instrument of the Ethiopian government presently.

After developing a decision framework based on farmer defined objectives including nutrition, the paper will respond to the following three questions:

1. Will farmers adopt the new technologies and in which combinations?
2. Do the new technologies improve the caloric intake and incomes of the farm households?
3. Which of the two policies, inventory or input credit, individually and/or in combination with the new technologies, have the largest impact on farmers' welfare?

The remaining sections of this paper are organized as follows. Study area description and household decision making are presented in the next section. In section 3 we discuss the different agricultural technologies and a marketing strategy. The theoretical and empirical models are presented in Section 4. Section 5 presents the empirical results and in section 6, concluding remarks, policy implications, and recommendations are provided.

2. Description of the Study Area and Household Decision Making

The Qobo valley is one of the high potential agricultural areas in Ethiopia with good volcanic soils and adequate rainfall in most years. Rivers and streams wash topsoil from the surrounding highlands and deposit it in the Qobo valley. Due to the annual sediment deposits, the alluvial soils in the valley are usually better than the soils in the highlands. Farmers in the valley also harness the rivers and streams originating in the highlands to increase soil moisture. With good soils and some water harvesting, the valleys have higher productivity than the hillsides and there is substantial migration of highland labor into the Qobo valley.

Unfortunately, with historically high population growth and no primogeniture (inheritance of the land by the first born), there has been continuing division of land. The average farm property size in the district ("wareda") is only 0.75 ha with 2.1 ha per household in the more prosperous valley. In the valley where the sample was taken, average household size was 5.6

members. It is also clear from the extremely low area available on the hillsides why labor comes down into the valley to help with seasonal operations.

At their current consumption levels, the farm households in Qobo (in the north Wollo zone of Amhara) in normal rainfall year meet only 60% of the World Health Organization (WHO) recommended level of cereal calories of 2200 Kcal per person per day (see Table 1).[1] The nutritional situation is even more precarious on the hillsides. From a social welfare perspective, any development policy must focus on raising these inadequate nutritional levels.

Technologies have been tested and are available; but how do farmers make decisions on adoption? We rely here on substantial field interviewing asking farmers how they make decisions. This is a behaviorist approach rather than following the traditional theoretical approach of defining a tradeoff between expected income and risk. This traditional approach is rejected for two reasons. First, neither in developed nor developing countries have the empirical techniques for defining the tradeoffs given conclusive results. To evaluate how well this traditional utility maximization theory performs, we would need to calculate the tradeoff between expected income and some representation of income variation to measure risk and then show that we could predict decision maker behavior better with these estimates than with other techniques. In one principal method to ascertain these tradeoffs farmers answer hypothetical questions about being indifferent between given levels of expected income and two or more different probabilities for receiving different incomes. For example: Do you prefer receiving income x or receiving either income y at 75% probability or income z at 25% probability? These income or probability levels are then varied to calculate the tradeoff coefficients. While this has been done with Midwestern farmers (Shapiro et al., 1992; Wilson and Eidman, 1983) with high educational levels, the results are suspect and do not adequately test the theory. Moreover, even explaining the concept to farmers in developing country would be formidable.

[1] Abate et al (2003) also reported an energy intake level of only 50 % of the WHO recommended daily allowances in the area.

There is another literature measuring risk aversion with money experiments (see Binswanger, 1980). These experiments are expensive and time consuming. Moreover, even allowing farmers to make choices with funds given to them is not the same as their choices with their own resources and income options. Finally, risk aversion coefficients are inferred from econometric or programming studies as if there were no specification errors or errors in variables. Clearly, there is often one or both of these errors biasing these estimates.

In conclusion we do not think that meaningful estimates are possible for risk aversion coefficients. In modeling, researchers generally present results for a range of risk coefficient values. This sensitivity analysis avoids the problem of not being able to estimate these tradeoff values for the preferred combination of expected income and risk. However, it also implies that we can never validate or reject this theory of decision making by comparing its predictions with other methods because the different risk aversion coefficients give a wide range of predictions. This standard utility combination of expected profit and some proxy for the riskiness of these activities then is generally accepted for its convenient mathematical properties of concavity and continuity. However, accepting a theory for its mathematical properties that can never be confirmed or refuted is not very satisfying especially if real decision makers apparently follow other rationales in making decisions.

Our second reason for preferring the behavioralist approach is that farmers in developing countries can consistently explain their decision making in terms of a series of goals to be met sequentially. Meeting these goals then is their expressed method of reducing risk before they maximize incomes (for these studies defining the same hierarchy of goals from fieldwork in different African countries, see Vitale and Sanders, 2005 for Mali; Abdoulaye and Sanders, 2006 for Niger; Uaiene, 2004 for Mozambique). We will define the goals as expressed by farmers in the following paragraphs and combine them into our model in section 4.

Individual and group interviews with farmers revealed that the farm households in the Qobo area maximize their profits, after first making sure that their post harvest income goal and subsistence food requirements are met. The post harvest income is the time based requirement immediately after harvest to pay for such urgent expenses as repayment of official and unofficial credit, payment of a land tax, payment of wages from the crop season (mainly for labor used at harvest), purchase of clothing and other gifts for family members as compensation for their labor contribution, medical and school fees, wedding and other cultural and religious feasts and celebrations.

When it is difficult to satisfy both harvest income and consumption storage objectives, farmers choose to satisfy their pressing harvest time cash income requirement first and then to rely on purchases in the market to meet their food requirement later in the year (Yigezu, 2005). These purchases later in the year either require off-farm work or remittances from family members, who have migrated.

As noted above, farmers in many other parts of Africa also make consumption and marketing decisions in the same way giving primacy to the harvest income goal and then to subsistence requirements by putting their staples into storage preferably to last until the next harvest. There is another farmer goal of producing their own staples rather than being dependent on the market for purchasing them. This goal will be discussed later in the methodology and validation sections.

3. Agricultural Technologies and a Marketing Strategy

Agriculture is the principal employer of the population in Qobo. Cereals and grain legumes are the primary crops grown. *Teff* (*Eragrostis tef*), sorghum, maize and chickpea are the most important by area coverage. Cereal yields are low – averaging a little over one ton per ha.

In low input agricultural systems, including in good agricultural resource base but overpopulated regions, soil fertility is being depleted. Hence, in the absence of a frontier, land productivity needs to be increased with higher input levels especially inorganic fertilizers. For fertilization to be effective, there also needs to be sufficient water availability at the critical stages of plant growth. Since teff and sorghum (generally semiarid crops) are principal crops in this region, there is already indication of the problem of water availability. So the principal focus of technological change is on increasing soil fertility and making more water available with inorganic fertilizer and a water harvesting technique (tied ridges or trenches).

Striga is associated with low soil fertility in many cereal and legume production regions. *Striga* is a parasitic weed that attaches itself to the host root and transpires at three times the normal rate of cultivated plants. Hence, water and nutrients are shunted to the parasite rather than to the plant thereby reducing yield (Shank, 1996).[2] Striga can be controlled by increasing soil fertility and/or with host plant resistance (Ejeta and Butler, 1993).

So the primary technologies to respond to the pressing constraints are first improved soil fertility, secondly increased water availability, and thirdly Striga resistance in new cultivars. The Striga resistance alone should be more useful in the poorer resource base regions outside the valley where the soils have been further depleted and it is more difficult for the farmers to purchase the inorganic fertilizers. For many farmers especially on the hillsides, the Striga resistant cultivars alone were provided. For these farmers, the water harvesting as with trenches can also be critical as it reduces erosion thereby protecting the topsoil.

Sales of *teff* and sorghum are the main sources of cash income for farm households in the Qobo area (Tesfahun, 2001). For the period 1994-2003, Yigezu (2005) estimated the expected annual household cash income from farming at Birr 1426 (US$163). [3] This income is in addition to the Birr 1290 (US$ 147) average household grain consumption from own production.

The harvest time cash income requirement is so pressing that farmers are compelled to sell their output immediately after harvest, at the time when prices frequently fall to their annual minimum. For instance, during the 2001/2002 agricultural calendar, a relatively good year,

[2] In the literature, sorghum yield losses due to *Striga* range from 40-100% (USAID, 2000). Ejeta and Butler (1993) estimate the crop loss due to *Striga* in semi-arid regions of low soil fertility (and in the absence of fertilization) to be between 65-100%.

[3] The exchange rate was 8.748 Birr/1 US Dollar in 2004 (WWP, 2004).

the average price of sorghum in Qobo showed an 85% increase between the months of December, which is the harvest season and August, which is the hungry season. The hungry season in Qobo is the period 6-10 months after harvest - usually between June and September. During the hungry season, farm households can run out of food and the markets are in short supply resulting in very high prices (SARC, 2004).

These technologies are in the early stages of diffusion with only 1.3% of the households in the study area having adopted any of the new technologies individually or in combination. Hence, here we evaluate potential adoption. Farmers with more productive resources and wealth lead the adoption process of a new technology then other farmers follow (Griliches, 1957). So we deliberately sample the best farmers expecting the rest with lower resources or management ability to at least partially imitate these better farmers. These better farmers are expected to be the most responsive to the new technologies.

A systematic sample of 101 farm households (38 adopters and 63 non adopters) with better access to land and animal power and closer to Qobo town was taken. This proximity to Qobo often results in higher off farm incomes. So these farmers have advantages both with respect to resource base and liquidity due to greater access to employment outside agriculture.

4. The Model

Farmers make decisions by ordering their priority goals. The lexicographic ordering of priority objectives approximates the preferences of the farm households in Qobo. However, unlike the textbook definition of lexicographic preferences (Deaton and Muellbauer, 1980), the goals of the farm households in the Qobo area have maximum values beyond which they become irrelevant and hence the next goal in order becomes the top priority. These maximum values were determined in the farm interviewing.[4]

[4]The harvest income goal was an overage over the different states of nature. In future work the income goals at the post harvest period will be determined for the different states of nature.

As a result, we have modified the lexicographic utility model calling it a capped-lexicographic model. In the Capped-Lexicographic Utility approach, the maximization of expected profit is undertaken only after the farmer has handled his risky environment by ensuring his expenditure requirements at harvest and setting aside staples for his subsistence requirement - specified here as caloric requirements (Figure 1).

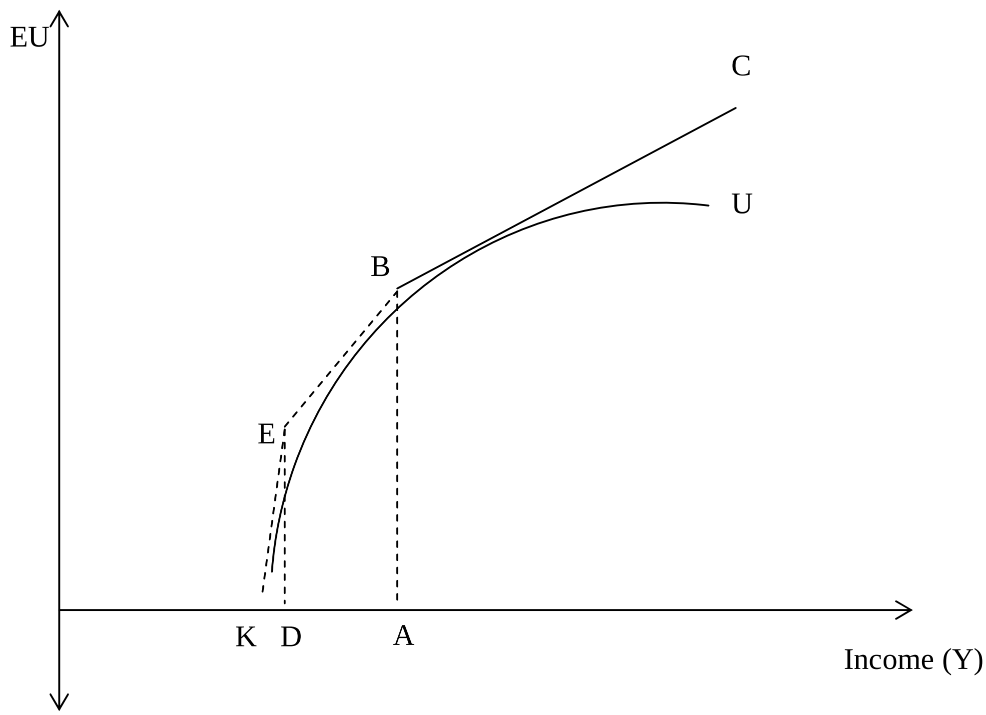

Figure 1: Graphical Exposition of the Capped-Lexicographic Utility Problem

Point D in Figure 1 represents the family's cash income goal for the necessary expenditures at harvest; (A-D) represents the monetary value of meeting the family's subsistence food requirement. Point A represents the monetary value of meeting both the cash and subsistence requirements.

In the modeling, we use the WHO minimum caloric recommendations at 100% levels in 80% of the cases, the relatively good states of nature. In the more adverse states of nature, 20% of the time, attaining this minimum consumption was infeasible. Hence, to avoid infeasible solutions, we sometimes had to reduce caloric goals to the maximum level that could be achieved with the given activities until there was a feasible solution. So farmers attempt to achieve as much of malnutrition reduction as they can (the feasible solution) and then they maximize income.

For Ethiopia, adequate nutrition is a critical goal. Note that in most developed and developing countries there is public intervention (and in developing countries NGO action) in the very adverse states of nature. In this Ethiopian study and in West Africa (Abdoulaye and Sanders, 2006) extreme drought or the very adverse state of nature occurred approximately 10% of the time. Due to the public sector intervention in these extreme drought years, farmers do not include it in their crop choice evaluation. However, in Ethiopia there is often insufficient food aid. So we include these types of years in the farmers' planning. Qobo valley is a prime agricultural area with better resources and more potential to harvest the runoff from the hillsides. However, these years are also very bad that it is not surprising that it is difficult to attain nutritional goals. The primary objective of the household is to attain the highest possible point on the curve KE (Figure 1). Once the household attains its harvest income goal (point E), then the next objective becomes to attain the highest possible point on curve EB. If the household meets both the income and subsistence goals (i.e., level B) then its objective becomes maximizing profit (i.e., attaining the highest possible level along the curve BC). In the calculation of profit, the harvest income goal and the value of subsistence consumption are also included. The smoothed curve approximation of the utility function is given by U, which is concave and hence indicates conceptually (without a formal proof) that the farm household is risk averse.

Mathematically, this optimization problem can be formulated as:

Max EU where, EU is expected utility and

$EU = (\alpha Y)$, if $Y \leq D$

$EU = (\alpha D + \beta(Y-D))$, if $D < Y \leq A$

$EU = (\alpha D + \beta(A-D) + \mu(Y-A))$, if $Y > A$, for $0 < \mu < \beta < \alpha$, where,

α, β and μ respectively are the slopes of the curves KE, EB and BC on Figure 1 above.

Risk aversion behavior is represented here by a linear objective function for income maximization with the two other lexicographic goals (harvest income and subsistence storage) as constraints. The empirical model is therefore formulated as:

$$Max\ (\pi) \tag{1}$$

Subject to the following constraints: note that all values are converted into their net present values using the lending rate of official financial institutions in the Qobo area which is 1.5% per month.

First and foremost, the revenue obtained from the sales of crops at harvest has to be at least as high as the harvest cash income requirement of the family, i.e.,

$$VCSH_k \geq HI_k \tag{2}$$

The amount of calories obtained from consumption from own production and purchases has to be at least sufficient to satisfy the total caloric requirement of the family with the exception previously noted for the two most adverse states of nature. We still try to satisfy this nutritional requirement with the new activities or combined activities. When we can not satisfy the caloric goal for these two states of nature, we release this constraint with sensitivity analysis to the highest nutritional level we can achieve.

$$\sum_i \ (CC_{ik} + CB_{ik}) *N_i \geq HS* CL \tag{3}$$

Equation 4 is an identity stating that part of total household production is sold at harvest to meet the harvest income requirement; then part is held for own consumption; and finally what is left is sold in the hungry season to maximize the household profit.

$$CP_{ik} = CC_{ik} + CS^{h}_{ik} + CS^{s}_{ik} \tag{4}$$

Equation 5 is the total output-yield identity.

$$CP_{ik} = \sum_q \sum_s \sum_j Y_{iqsjk} * X_{iqsj} \tag{5}$$

Equation 6 is the resource constraint which states that all resources utilized in any state of nature can not exceed the resources available to the farmer.

$$\sum_{i,q,s,j} b_{iqsj} * (x_{iqsj}) \le b \tag{6}$$

Equations 7 and 8 describe how expected profit is defined in this study. In Equation 7 expected profit is the probability weighted average of profits in all states of nature. In equation 8, adjusted profit in each state of nature is the gross revenue from sales in the hungry season minus the sum of the cost of production minus the adjustment for purchasing food in the hungry season. To satisfy the consumption constraint, we need to allow the farmer to purchase food in the hungry season.

$$\pi = \sum_k \Pr ob_k * PROFIT_K \tag{7}$$

$$PROFIT_K = \sum_{iqsj} (PS_{i,k} * CSS_{ik} - c_{iqsjk} * X_{iqsj}) - \lambda * VCBS_k \tag{8}$$

The value of the self reliance factor (λ) is initially set to 1 at which point the marginal cost of own production is equal to the expected price for purchasing food later in the year. However, farmers often have an aversion to being forced to purchase part of their staple food supply in most years. So we increase λ to higher levels enabling farmers to push their own marginal cost of production of their staples higher and therefore to be less market dependent for their staples even in adverse years. This process is continued to validate the model until the crop areas and quantities of the staples purchased in the different states of nature in the model are consistent with the observations of farmer behavior in the region.[5]

Equation 9 gets us back to a better definition of farm income by eliminating the term for buying food staples from the definition of income. We also add into income the harvest income requirement and the value of the subsistence set aside in storage.

$$ENFI = \sum_k \Pr ob_k * (PROFIT_K + \lambda * VCBS_k + VCSH_k + VCC_k) \qquad (9)$$

Equation 10 includes the expected net household income from the farm and the expected income from other sources. Equation 10 is the conventional disposable household income.

$$ENHI = ENFI + \sum_k \Pr ob_k * OI_k \qquad (10)$$

Equations 11 and 12 are simple identities which calculate the values of crops purchased during the hungry season and the crops sold at harvest respectively feeding into equation 9 above.

$$VCBS_k = \sum_i \quad ((PS_{ik})(CBS_{ik})\,) \qquad (11)$$

$$VCSH_k = \sum_i \quad ((PH_{ik})(CSH_{ik})) \qquad (12)$$

[5] Note that we are subject to the same problem of assuming no errors in variables or specification errors here that we criticized earlier.

Variable/Parameter Definitions

Variable/ Parameter	Description
π	Expected profit
$Prob_k$	Probability of state of nature k where $\sum_k \Pr ob_k = 1$
$VCSH_k$	Value of crops sold at harvest in state *k*
HI_k	The minimum family cash requirement immediately after harvest in state *k*
$CC_{i,k}$	Crop type and variety *I* consumed from own production in state *k*
$CB_{i,k}$	Crop type and variety *I* purchased in state *k*
N_i	The calories per unit of crop type and variety *I*
HS	Household size (adult equivalent)
CL	The minimum amount of calories required per adult person per year. This amount may not be achievable during the adverse years and if so, simulations will be made to determine the maximum achievable levels during those years.
CP_{ik}	Total quantity of crop type and variety *I* produced in state *k*
CS^h_{ik}	Quantity crop type and variety *I* sold in the harvest season (h) in state *k*
CSS_{ik}	Quantity crop type and variety *I* sold in the hungry season (s) in state *k*
Y_{iqsjk}	Yield of crop type and variety *I* planted using technology *j* on one hectare of land with soil type *q* and *Striga* infestation state *s* in state *k*
X_{iqsj}	Land in hectares allocated for the production of crop type and variety *i* planted using technology *j* on crop land with soil type *q* and *Striga* infestation state *s* regardless of the state of nature. The land allocation variable does not have the state of nature subscript because planting

Variable/ Parameter	Description
	decisions are made before the realization of the state of nature.
b_{iqsj}	Resource type *b* required to produce crop type and variety *I*, on one hectare of land with soil quality *q*, state of *Striga* infestation *s* using technology *j*
b	Amount of resource type b available for the farm household
$PROFIT_K$	Profit (profit after meeting the lexicographic goals) in state k
$(\lambda$ -1)* 100%	The self-reliance factor (i.e., the amount as a percentage of the expected market price later in the hungry season) that farmers are prepared to pay in order to reduce dependence on purchases for own consumption.
ENFI	The expected value of net farm income (including the value of crop sales at harvest, the value of crop purchase during the hungry season multiplied by the risk adjustment coefficient, and the value of crop consumption from own production)
ENHI	The expected value of net household income (which is the sum of the expected net farm income and the expected non farm income)
PS_{ik}	Price of crop type and variety *i* in the hungry season (s) in state of nature *k*
PH_{ik}	Price of crop type and variety *I* at harvest season (*h*) in state of nature *k*
OI_k	Other (non farm) income in state of nature *k* which (as discussed in Section 2.2.1) is exogenously determined
c_{iqsjk}	Cost per ha of producing crop type and variety *i* using technology mix *j* on a crop land of soil type *q* and status of *Striga* infestation *s* in state *k*

Variable/ Parameter	Description
CB^{s}_{ik}	Quantity of crop type and variety *i* purchased in the hungry season (s) in state *k*
VCC_k	Value of crops consumed from own production in state *k*
$VCBS_k$	Value of crop bought in the hungry season in state k

Model Validation

If farmers set λ equal to one, then they produce their staples up to a marginal value product of the expected price across seasons and they would have put most of their land into teff which always fetches very high prices. However, farmers are observed producing most of their basic staple cereals (sorghum and maize) instead. They demonstrate that they do not want to depend upon the market for these crops. A λ value of 1.45 results in land allocation with the smallest percentage deviations from the observed land use both from our sample and those reported in Tesfay (2007) (Table 2). The higher own food production premium enables farmers to continue producing their own food until their costs of production are 45% higher than the expected food purchase prices.

Also at λ=1.45, farmers almost fully rely on their own production for consumption (Table 3). Personal discussions with the extension agents and experts in the Qobo Wereda Agriculture Bureau also revealed that the farmers in Qobo area are very set in their desire to rely on their own production for consumption. Theoretically, if farmers are relying on own production merely for the purpose of market risk aversion, then we would expect that the product of the expected market price (P^e) and λ to be equal to the price in the most adverse year. However, in the case of farmers in Qobo, the price in the most adverse year is on the average 16% lower than the λ* P^e values (Table 4). This shows that there are other reasons for the farmers to insist on producing for their own consumption. The farmers themselves (all of them male) have reported during the interviews that it is a taboo for a farm household to depend on purchases for food and if they do, even their own wives would criticize them. In fact, almost all women we talked to during the interview said “yeshemeta ehel aybereketem” expressing their belief that “purchased food is not blessed or does not last long”. Hence, this social stigma accounts for this discrepancy.

With this greater demand to be self reliant (λ value of 1.45) income is 22% lower than in the case without this self reliance factor (λ of 1). Yet, even with the self reliance factor income is still 27% higher than the average of the observed net household incomes for the years 2002 and 2003. Why? As the observed years were both above average in rainfall and other production conditions, prices during those years were observed to be lower than the expected price. The price effects on income are often higher than the yield effects. In the good rains in 2001/2002, farmers in many parts of Ethiopia had bumper harvest but faced a collapse in prices at harvest. The good season price collapse results from the inelastic demand for staples once the principal use as food is satisfied. So these income estimates, though higher than recently observed incomes, are still consistent with normal incomes for years of price collapse.[6] Model C (Table 3) with a λ value of 1.45 is therefore considered to be the best representation of farmers’ preferences in decision making in the Qobo area.

5. Results

Farmers consume a substantial amount of the least nutritious and most expensive crop (teff). Reallocating consumption, farm households in Qobo could attain the WHO minimum calorie goals 80% of the time even without the new technologies and/or inventory credit. But why are actual consumption levels so much lower than 80%? Our principal hypothesis is that farmers’ lack awareness about the nutritional values of the different crops they consume.

[6] To respond to this phenomenon new markets for processed grain as food and feed are required but this is beyond the scope of this paper.

Given farmers' present food consumption habits, introducing the water harvesting technique of tied-ridges alone would increase the expected net household income[7] by 13% with the tied ridges being utilized on 2 ha, 95% of the crop area (Table 5). Nutritionally, the farmers would be able to fully meet the WHO recommended level of calories in the second most adverse state of nature (10% probability) and improve nutrition by 14% in the most adverse year, which also has 10% probability (Table 6).

If fertilizer alone were to be introduced in the Qobo area, the representative farm household would adopt it on 0.94 ha (44% of total cultivated land area). Expected net household income then increases by 7% (Table 5). The effect on calorie consumption in the two adverse years is: a 9% increase in the second most adverse state of nature (Table 6) and no nutritional effect in the most adverse state. Note that in most of the world subject to the types of rainfall shortage as in this region in the most adverse state, farmers receive some food or cash transfers from government or NGO action. This intervention was not included in this analysis.

The simultaneous introduction of tied-ridges and fertilizers will increase the expected net household income by 18% (Table 5). Nutritionally, the farm households can fully meet the WHO recommended level of cereal calorie for the second most adverse state of nature and reach 82% of the WHO recommendation (Model H in Table 6) for the most adverse state of nature. For the most adverse state of nature, this was an increase of cereal calories by 30%.

The typical farmer will adopt the new *Striga* resistant cultivars[8] by themselves on 0.14 ha replacing the local short season sorghum varieties according to model results (Table 5). But farmers only plant short season cultivars when the rains are late, approximately 60% of the time. Consequently, the expected income effect is low with an increase of only 1% in net

[7] Net household income (NHI or the gross margin in linear programming terms) is defined as the sum of: income from farming, the value of own crop consumption, and other family income less production expenses (which include cost of hired labor, seed cost, and other input costs). So, net income is the sum of profits and returns to family labor and land.

[8] The Sirinka Agriculture Research Centre (SARC) in North Wello of the Amhara region tested for the adaptation of three sorghum varieties developed by Gebisa Ejeta at Purdue University (P-9401, P-9403, and P-9404 locally called Gobiye, Abshir and Birhan respectively). These varieties are resistant to the parasitic weed *Striga*. In 2001, the country wide Integrated *Striga* Management (ISM) program introduced the *Striga* resistant varieties along with complementary technologies (inorganic fertilizer for fertility improvement and tied-ridges for water retention) to the Qobo area. From our survey, 67% of the cultivated areas in the study area are infested with *Striga*.

household income. The new *Striga* resistant sorghum varieties have a similar growing period (3.5-4 months) to that of other improved, short season sorghum varieties in the region, *Wediaker* and *Meko*. All the short season materials mature 4-5 months earlier than the long season varieties. So a major conclusion for breeding might be to focus on the medium and long season cultivars rather than attempting to get both drought escape through earliness for the Striga resistant cultivars. The water harvesting is reducing the threat of drought and the farmers prefer the higher yields of their longer season cultivars when this threat is reduced. Fertilization also reduces the Striga problem as it is a low soil fertility phenomenon.

Due to consumers' preferences for the local long and intermediate season sorghums, there is a substantial price discount (on the average 42% for the SRVs and 31% for the local short season variety called Wediaker. However, *Wediaker* has come a long way since its first introduction during which it also had even much higher price discounts. Over time, consumers and farmers developed a taste for it and the prices have increased (though not still as high as those of the local long and intermediate varieties) accelerating its adoption. Hence we anticipate the price differential of the *Striga* resistant sorghum varieties with respect to the other sorghums to decline. However, for such price increases to induce increased adoption, the price of the SRVs has to be at least 8% higher than that of Wediaker.

The introduction of the whole integrated Striga management (ISM) technology package (SR varieties, tied-ridges and fertilizers) results in the same level of nutritional improvement for farmers but marginally higher level of expected net household income (18%) as compared with the introduction of tied-ridges and fertilizers alone (Table 6). So here again the second most adverse state attains adequate calories and the most adverse state 82% of requirements.

Without the combination of the new technologies, inventory credit increases the expected net household income by 13% as compared to the base case (Model J in Table 5). This is less of an income increase than the combination of tied ridges and fertilization. The introduction of inventory credit by itself has no effect on the available cereal calories in the two most adverse states of nature (Table 6).

If inventory credit were introduced along with the whole technology package, expected net household income would increase by 31%, which is 9% higher than the case with the introduction of the three combined technologies without inventory credit (Table 5). Nutritionally, the sample farm household will be able to fully meet the WHO calorie recommendation in the second most adverse state of nature and 82% of the WHO recommendation in the most adverse state.

The model results show that there is no advantage (neither in terms of available calories nor farm income) to the provision of input credits if farmers have to repay them at harvest. The experience in Ethiopia is that input credit is provided in kind as inorganic fertilizer and farmers have to repay their input credit at harvest. This results in very low prices even financial losses when prices collapse in good rainfall years. However, net expected income increases by 22% if all the technologies are introduced with a flexible input credit. In this case farmers can delay repayment of their input credit until prices recover during the hungry season. Hence, the input credit is turned into an inventory credit program.

6. Conclusions

The combination of the three technologies gives the highest expected benefits to farmers both in terms of nutritional intakes and income. The introduction of the water harvesting technique along with inorganic fertilizers and the SR varieties eliminates the risk of losing money during the second most adverse year. In the most adverse year however, the use of inorganic fertilizers even with a water harvesting technique would result in monetary loss. As noted before, farmers all over the semiarid world need public or NGO intervention for these worst rainfall years. In the US, the public sector finances over one half the costs of risk insurance for farmers in semiarid regions and provides disaster assistance for the very adverse rainfall years (Dismukes and Glauber, 2005).

The introduction of inventory credit enables farmers to exploit the high seasonal price fluctuations to their own advantage. The farm households in the Qobo area would benefit the most if the ISM technology package is introduced along with inventory credit. Hence, development policies that aim at improving the nutritional and income status of the farm households[9] in the moisture stressed Amhara region in general and in the Qobo area in particular, need to not only facilitate the adoption and diffusion of the three technologies, but also introduce inventory credit to help farmers take advantage of the seasonal price changes.

In the long run however, the increase in income due to the introduction of inventory credit will decrease once many farmers delay sales until later. As inventory credit becomes widespread, the price difference between months will approach the costs of storage plus the opportunity costs of capital. So it will be necessary to search for other marketing strategies to obtain a continuing price incentive to accelerate diffusion of this moderate input package. One method is to begin facilitating the development of the food and feed processing sectors to prepare for the diminishing returns to inventory credit.

The benefits to farm households of input credits, as administered currently, are low because farmers have to repay their credits immediately after harvest at which time prices generally fall to their annual lows. If farm households are to benefit from the provision of input credits, the credit administration needs to be flexible enough to allow farmers to delay their repayments until later during the hungry season (six to eight months after harvest), generally the time of substantial price increase. This modification of credit programs turns input credit programs into a type of inventory credit.

The agronomic success of the SRVs on *Striga* infested fields is evident. The benefits of this agronomic success can be increased if the preferred consumption features of the local long and intermediate sorghum varieties (reflected in their higher market prices) could be incorporated into the SR varieties and hence the prices of the *Striga* resistant cultivars increased. Moreover, farmers will want to exploit the higher yield potential of local long season and intermediate sorghum varieties in the good states of nature (30% probability).The risk of the adverse states is also reduced by the water harvesting technique. Incorporating the *Striga* resistance element into these medium and long season varieties (or developing a new

[9] Note that this was a sample selected from the best farmers expecting them to be imitated by other farmers but to be the first adopters. So we would need to do further work to evaluate the constraints faced by farmers on the hillsides and those with lower resource base.

long season *Striga* resistant sorghum variety) would give farmers a full range of choices with all the desirable qualities.

Our results show that current food preferences for teff make it more difficult for the farm households to meet nutritional goals. Consumer education may help in modifying these habits. There also are undoubtedly data problems due to farmers' inabilities to remember all expenditures and the lack of social acceptability of some expenditures leading to failure to report. There is undoubtedly a return in improved nutrition from delivering improved nutritional information to farmers and from obtaining more accurate consumption data from farmers.

Acknowledgements

We thank T. G. Baker and W.A. Masters for their help in the mathematical formulation and graphical exposition of the capped-lexicographic utility. We also thank J. M. Lowenberg-DeBoer for his constructive comments on an earlier version of this paper. Our special thanks also go to INTSORMILL funding this research including the primary data collection.

BIBLIOGRAPHY

Abate, G., Haidar, J. and Degene A., 2003. Nutrition survey report in Harbu and Kobo Weredas, North Wollo Zone. The Impact Study Group. The Joint Ethio-Danish Development Program. Addis Ababa, Ethiopia.

Abdoulaye T. and Sanders, J. H. 2006. New technologies and improved marketing for traditional food crops: millet in Niger. *Agricultural Systems.*Vol. 90: pp. 272-292.

ACC – United Nations, Administrative Committee on Coordination/ Sub-Committee. 1997. Third Report on World Nutrition Situation. WHO, Geneva, Switzerland.

Binswanger, Hans. 1982. Empirical estimation and use of risk preferences: Discussion,"*American Journal of Agricultural Economics*, pp. 391-393

Bouis, H.E. 1996: Enrichment of food staples through plant breeding: a new strategy for fighting micronutrient malnutrition. *Nutrition Review*. Vol. 54, pp:131-137.

Deaton, A. and Muellbauer, J. 1980. *Economics and Consumer Behavior*, Cambridge University Press.

Dismukes and Glauber, R. Dismukes and J. Glauber. 2005. Why hasn't crop insurance eliminated disaster assistance?, *Amber Waves* **3** (2005) (3), pp. 34–41.

Divender, S. 2007. Flogging a dead horse. Biofortification is no cure for hunger. http://www.indiatogether.org/2003/nov/dsh-gates.htm

Ejeta, G. and Butler, L. G., 1993. Host plant resistance to Striga. *International Crop Science I*. Crop Science Society of America." Madison Crop Science Society of America, Madison, Wisconsin. pp. 551-559.

Griliches, Z. 195). Hybrid Corn: An exploration in the economics of technological change. *Econometrica.* vol. 25 (October).

IFPRI – The International Food Policy Research Institute. 2002. *Biofortification: Harnessing Agricultural Technology to Improve the Health of the Poor*. IFPRI, Washington D.C.Shapiro,

B. I., Brorsen, B. Wade and Doster, D. Howard. 1992. Adoption of double cropping soybeans and wheat, *Southern Journal of Agricultural Economics*, 33-40.

Sirinka Agricultural Research Center – SARC. 2004. Annual consumer price reports. Sirinka, Ethiopia.

Tesfahun G., Werede F., Belete E. and Girma, A. 2001. Farming systems of Qobo. Initial findings of an informal survey. Sirinka Agricultural Research Center, Sirinka, Ethiopia.

Tesfay, H. 2007. Assessment of institutional setup and effect of household level water harvesting in ensuring sustainable livelihood: Case study of Kobo, Almata and Kilte Awlaelo Woredas in Amhara and Tigray Regions of Ethiopia. Drylands Coordination Group, Report No. 52. Miljøhuset, Norway.

Uaiene, R. 2004. Maize and sorghum technologies and the effects of marketing strategies on farmers's income in Mozambique." Unpublished masters thesis. Purdue University, West Lafayette, U.S.A.

USAID. 2000. Amhara National Regional State Food Security Research Report. Collaborative research support programs team, USAID, Addis Ababa, Ethiopia.

Underwood, B.A. 1999. Micronutrient deficiencies as a public health problem in developing countries and effectiveness of supplementation, fortification, and nutrition education: Is there a role for agriculture? In *Improving Human Nutrition Through Agriculture: The role of International Agriculture Research*. International Food and Policy Research Institute (IFRPI). Washington, D.C.

Vitale, J. and Sanders, J. 2005. New markets and technological change for the traditional cereals in Sub-Saharan Africa: The Malian case." *Agricultural Economics*, 32: 111-129.

Welch, R. M. and R.D. Graham. 1999. A new paradigm for world agriculture: Meeting human needs. Productive, sustainable, nutritious. *Field Crop Research*. Vol. 60, pp:1-10.

Wilson, P. N. and Eidman, V. R. 1983. An empirical test of the interval approach for estimating risk preferences, *Western Journal of Agricultural Economics*, 8: 170-182

WWP. 2004. (http://wwp.greenwichmeantime.com/time-zone/africa/ethiopia/currency.htm)

Yigezu A. Yigezu. 2005. Technological and policy changes for improving farmers' welfare in the Amhara region (Ethiopia)." Unpublished masters thesis. Purdue University, West Lafayette, U.S.A.

Table 1: Crop Consumption (in Kg) by the Average Sample Farm Household in Different States of Nature

		States of Nature			
		Very good	Good	Average	Bad
Crop type	Probability	0.1	0.2	0.3	0.4
Teff		487	401	366	164
Sorghum		521	559	552	500
Maize		100	100	100	50
Chickpea		60	60	60	36
Total calories (in millions)		1.84	1.78	1.71	1.21
Consumption as % of the WHO cereal calorie requirement		72	70	67	47

Source: Yigezu (2005)

Notes: The initial eight states of nature were reduced to four here to simplify the farmer response to the questions about yields for different states of nature. To focus more on the nutritional inadequacies we further break down the bad state of nature into three cases. In the first case, with approximately 20% probability, the rainfall is late but then adequate. In these years farmers specialize in short season crops. Yields are reduced but without serious nutritional problems. The second two cases are the focus of the nutritional analysis. In the second case at 10% probability there are good early rains but then the rains stop before the long season crop matures. In the third and the most adverse years, which also occurs 10% of the time, rains start and stop early. This state of nature is the most serious for yield decline and resulting nutritional problems.

Table 2: Observed and Modeled Land Allocation by Crop Type and Variety in the Qobo Area (% of Total Area)

	Observed Areas values		Base Model Estimates			
	Average from another study (for 2006)[j]	Average of our sample farms (Average of 2002 and 2003)	Model A λ=1	Model B λ=1.40	Model C λ=1.45	Model D λ=1.50
Crop		%	%	%	%	%
Teff	47.63	60.28	60.33	49.81	48.83	48.83
Short season sorghum		9.51	5.89	17.10	17.10	17.10
Intermediate sorghum		15.84	16.73	16.73	16.73	16.73
Long season sorghum	46.32[k]	11.89	17.06	13.55	13.55	12.62
Striga resistant varieties (SRVs)		NA	NA	NA	NA	NA
Chickpea		1.08	0.00	0.61	1.59	2.06
Maize	6.05	1.41	0.00	2.20	2.20	2.66
Total	100.00	100.00	100.00	100.00	100.00	100.00

Sources: Yigezu (2005): Survey Results and Model Estimates; Tesfay (2007).

Notes:

1. In terms of area allocation, Model C best depicts the reality. Hence λ=1.45 indicates that the benchmark farm household is willing to pay 45% higher price than the average market price to avoid dependence on the market for own consumption.
2. As discussed in the previous sections, even if they were to aim at achieving the WHO level of cereal calories, farm households in the Qobo area could not meet it especially in the two most adverse states of nature. Hence, all models A-D are built based on the maximum attainable levels of calorie intakes from grains which respectively are 52% and 82% for the most adverse and second most adverse states of nature and 100% for the rest of the states of nature.

[j] These figures are for the year 2006 which can be characterized as a good year. The author (Tesfay, 2007) reported the allocation of total land including those used for horticulture. Horticultural and lands under other crops and fruits have been omitted here. Only the area in the most important crops is considered in this study.
[k] Data is not disaggregated by variety.

Table 3: Quantity (Kg) of the Main Food Staples Purchased at λ Values of 1 and 1.45

Crop Type	States of Nature							
	Very good		Good		Average		Bad	
	λ=1	λ=1.45	λ=1	λ=1.45	λ=1	λ=1.45	λ=1	λ=1.45
Teff	0	0	0	0	0	0	164	164
Sorghum	0	0	315	0	552	0	275	0
Maize	100	0	100	0	100	0	50	50
Chickpea	60	60	60	60	60	0	36	36

Source: Model Predictions

Table 4: Prices of Crops in the Qobo Market (2004)

Crop type	Crop name	Expected prices(P^e)	Opportunity cost of own food production (λ=1.45)*Pe	Bad year Prices
LSS	*Abola*	1.275	1.84875	1.5
ISS	*Jigurte*	1.055	1.52975	1.3
SLS	*Wediaker*	0.875	1.26875	1.15
SRV	*Gobiye & Abshir*	0.735	1.06575	0.95
Chickpea	*Shimbra*	1.765	2.55925	2
Maize	*Bekolo*	0.995	1.44275	1.25
Teff	*Sergegna teff*	1.84	2.668	2.25
Average		1.22	1.769	1.4857

Where:

LSS = Long Season Sorghum varieties

ISS = Intermediate Season Sorghum varieties

SLS = Short Season Sorghum varieties

SRV = *Striga* Resistant Sorghum Varieties

Source: Sirinka Agricultural Research Center: Monthly agricultural commodity prices, 2004.

Table 5: Income and Land Allocation Effects of the Individual and Combined Use of the Three Technologies and Inventory Credit

	Model Estimates							
	Base Case	SRV alone	Fertilizer alone	Tied-ridges alone	Tied-ridges and Fertilizers	All three technologies	Inventory credit alone	Inventory Credit and the whole technology package
Item	Model C	Model E	Model F	Model G	Model H	Model I	Model J	Model K
Expected net household income in Birr	4381	4387	4669	4930	5225	5231	4956	5722
Expected net household income in US$	501	501	533	563	597	598	566	654
Crop	%	%	%	%	%	%	%	%
Teff	48.83	47.48	56.64	50.14	54.579	53.598	55.000	54.720
Short season sorghum	17.10	10.23	12.86	12.66	7.430	3.832	11.636	3.692
Intermediate sorghum	16.73	16.73	16.74	11.36	11.355	11.355	16.729	11.355
Long season sorghum	13.55	15.37	12.35	21.50	24.393	22.570	13.271	22.430
Striga resistant varieties (SRVs)	NA	6.40	NA	NA	NA	5.794	NA	4.720
Chickpea	1.59	0.98	0.61	1.87	0.841	0.841	1.075	0.841
Maize	2.20	2.80	0.80	2.48	1.402	2.009	2.290	2.243
Total = 2.14 ha	100.00	100.00	100.00	100.00	100.000	100.00	100.00	100.00

Source: Model Results.

Notes:
With the introduction of the whole technology package, total land allocation to the short season sorghums (SRVs and local short season sorghum) is reduced because the returns to fertilizers are the highest with *teff* and the returns to tied-ridges are the highest with the long season sorghums. Area of both teff and tied ridges are then increased. NA means Not Applicable because the SRVs are not available options to farmers in these cases.

Table 6: Caloric Effects of the Individual and Combined Introduction of the Three Technologies and Inventory Credit

State of nature	Model Estimates of the Maximum Attainable Level of Cereal Calories for the Farm Households in the Qobo area (as % of the WHO recommended level of cereal calories)							
	Base Case	SRV alone	Fertilizer alone	Tied-ridges alone	Tied-ridges and Fertilizers	All three technologies	Inventory Credit alone	Inventory Credit and the whole technology package
	Model C	Model E	Model F	Model G	Model H	Model I	Model J	Model K
Most Adverse	52	52	52	66	82	82	52	82
Second Most Adverse	82	82	91	100	100	100	82	100
Expected Attainment*	93	93	94	97	98	98	93	98

Source: Model results.

Notes: Currently (in the base case scenario), the sample average farm household in the Qobo area can meet the WHO recommended level of cereal calorie intake in all but the most adverse and second most adverse states of nature which combined have a 0.2 probability of occurrence. In these two most adverse states of nature, however, the maximum attainable levels of cereal calories are 52% and 82%. Hence, the values in the Base case column in Table 6 are the maximum attainable levels and not the observed values. The observed calories are the calorie equivalents of the amount of different crop types consumed by the farm households for the different states of nature as reported during the survey (see Table 1 earlier).Maximum attainable calorie levels are those, which the farm household can afford to consume without any change to their consumption habits or technology, but by giving priority to food after meeting their post harvest income needs. This implies that the expenses on unacceptable extravagance by the household heads and other unreported expenses would have to be reallocated to food. Expected attainment refers to the expected level of cereal calorie attainment over all the states of nature as a % of WHO recommendation.